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Research Article

A Mixed Methods Approach for Analyzing the Imagery of a Novel Science

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Abstract

Though scientists and governments have realized the potential of nanoscience and nanotechnology, much of the public is still unfamiliar with nanoscience and current advancements in the field. Scholars have found that one of the most persuasive powers of science is how it is visually portrayed to the public. However, among the few articles that examine the visual rhetoric of nano images there is no comparison between these rhetorical evaluations and the results of qualitative audience reception studies. The purpose of this study was to demonstrate how various types of nano images operate rhetorically to influence public perception. It used a mixed-method approach, combining critical rhetorical analysis and in-depth interviews to allow for a more complex analysis about the relationship between image and viewer. Findings suggest that images created by professional artists, or "fine art" images may be the most attractive types of images for a lay viewer. This information may help scientists understand how the public's knowledge and perception of nanoscience is shaped through nano imagery.

Key Words: Visual rhetoric, visual communication, nanoscience, public perception

论文摘要

尽管纳米科技的潜力已受到科学家和政府部门的重视，但公众对其的认知程度还很有限。学者研究表明，当科学以视觉形式展示给公众时最具影响力。然而，为数不多的、有关纳米影像视觉修辞的文章并未涉及修辞评估和质化受众研究结果之间的对比。这篇论文旨在证明不同类型的纳米影像如何利用修辞功能影响公众认知。此项研究混合使用了批判性修辞分析和深度访谈两种方法，对影像与受众的关系进行更为复杂的分析。研究结果显示，由职业艺术家创作的影像或者美术类影像对普通受众最具吸引力。这一信息可以帮助科学家理解纳米意象如何促进公众对纳米科学的了解与认知。

关键词：视觉修辞，视觉交流，纳米科学，公众认知

Scientists and governments recognize the potential of nanoscience research, and countries have instituted initiatives to promote the multidisciplinary science in their universities and labs. While the rate of discovery has increased dramatically, much of the public is still unfamiliar with the field. As discoveries in nanotechnology continue and use of nanoparticles becomes more common, public perception of the science will become increasingly important in determining whether or not government and private industry support the research. One of the most persuasive ways science can communicate and introduce a novel science to the public is through visual imagery (Baigrie, 1996).

What makes nanoscience images especially interesting and fundamentally rhetorical is that they have to be actively created given that nanoparticles are not even visible through optical magnification. Instead, the microscopes have to reflect topological information to a reader that creates a 3-dimensional surface map. Scientists and computers interpret information from the surface map in order to generate a visual image. Value and color are then added to the image to help audiences distinguish meaningful elements. Because of this interpretive process, the image does not finally appear as it physically exists. For instance, the added color is false because a world at the nanoscale is colorless (the nanoscale is smaller than wavelengths of light).

So, how does interpretive manipulation of color, light, form and contrast, influence the public perception of nanotechnology? Much of the information the public absorbs is visual, and this, as well as the textual messages, influences their conclusions. Furthermore, the visual design and imagery presented on particular websites where the images exist (for example university blog sites, news sites, online science magazines, etc.) may determine whether or not the public decides to remain long enough to read the information. The purpose of this study was to demonstrate how different types of nano images operate rhetorically to articulate public perception.

Because there is a wide variety of nano imagery and various audiences involved, this study concentrates on images representative of schematics, documentation, fantasy, and fine art—modeled after Chris Robinson's image typology (2004). Robinson is a faculty member in the Department of Art at the University of South Carolina (USC) and is also an active member of the USC NanoCenter.

This study considered how the images function rhetorically only in regards to the Western lay audience as opposed to scientists or experts in the field. In order to avoid having participant reactions dominate or drive the rhetorical analysis, the images were analyzed rhetorically before being shown to a sample of the public in order to analyze their reaction. This study contributes to the field of both social science and visual rhetoric by further demonstrating the influence of scientific images on the public and the rhetorical nature of those images. Landau, Groscurth, Wright, and Condit, (2008) call for this type of study explaining,

> Audience studies on the impact of visual images on public understandings of nanotechnology are absent. There is a gap in the emerging academic literature on nanotechnology, on science in general, and, crucially, on assessing how nanotechnology will affect the general population, especially considering the significance of visual scientific images in history and in contemporary mediated public persuasion (p. 2).

Therefore, this study contributes to the literature by offering ways to better visually communicate nanoscience information to the public using a combination of both visual rhetoric analysis and qualitative interviews. Using findings from the interpretative analysis and the feedback from subjects within the study, this study illustrates in what ways audiences react to the various typological categories.

Public Understanding of Science and Influence of Images on Perception

Over the past twenty years, the public's scientific knowledge and expertise has been increasingly important in social and political policymaking. Because of the power of public opinion, much energy has been devoted to studying issues of public engagement in order to facilitate informed participation. Even with these engagement efforts, much of the public's understanding of science is developed through its experience with popular scientific literature. Recent scholarly studies have begun to criticize the non-factual rhetoric of popular scientific

literature as well as the persuasive power of images in this literature as distributed to the public, (Baigrie, 1996: Dombrowski, 2003; Farnsworth and Crismore, 1991; Lefevre, Ren, and Schoepflin, 2003). Findings from these studies suggest that images contribute to public acceptance of scientific developments even more than verbal arguments.

What is Nanoscience?

Nanoscale science or "nanoscience" is an emergent field that examines the principles of matter at a molecular level. Nano is the prefix for 1 billionth. In 1990, IBM scientist Don Eigler formed the IBM logo out of xenon atoms demonstrating to other scientists the potential for exact manipulation of atoms at the molecular scale. Because of the wide range of elements, and combinations, the potential uses for nanotechnology continue to grow. Nanotubes for instance, are highly conductive and strong so they are useful for making computer chips and memory storage devices. More recent uses of nanotechnology exist within automobile manufacturing to create stronger parts; in textile manufacturing to increase stain resistance, and softness of materials; in cosmetics to create various beauty products such as skin cream and suntan lotions (Hearn, 2003).

Public Awareness of Nanoscience

Although the media has made some effort to cover nanoscience in their reporting, a study released in 2008 by the Project of Emerging Nanotechnologies (PEN) and Peter D. Hart Research (2008), indicated that almost half of U.S. adults had heard nothing about nanotechnology. A more recent poll published in 2012 by Harris Interactive indicates that these numbers have not changed much, and in some demographics, awareness has actually decreased (Harris Polls, 2012). According to these findings, public awareness about nanotechnology has not measurably changed in the United States since 2004 when Hart Research conducted the first poll on the topic on behalf of the PEN.

Rhetoric and Science

Over the past two decades, rhetorical studies have depicted the process of scientific research and application as a "highly social discursive process" and one of rhetorical activity (see Faber, 2006; Baake, 2003; Battalio, 1998, Coppola & Karis 2000; Hass & Kleine, 2003). Since at least the 17th century, science explicitly denied any connection to the rhetorical tradition. However, in the past few decades science has been the subject of rhetorical interpretation with foundational studies such as John A. Campbell's rhetorical analysis of Darwin's *The Origin of Species* and Maurice A. Finocchairo's *Galileo and the Art of Reasoning*. Rhetorical scholars coming from a conservative standpoint (where there is the belief that communication texts are designed to persuade members of scientific communities and that the scientific findings themselves are not objects for rhetorical scrutiny) examine topics such as: various modes of inquiry, the ethos of scientific practitioners, the organization and persuasive nature of scientific publications as well as scientific discourse and debates in various mediums.

Nanoscience and Rhetoric

Research on the rhetoric of nanoscience has not been extensive. Berube (2004) uses a case study to examine the rhetorical strategies used by proponents of a particular nanoscience technology and how these messages are spun out to the public. In the case of the self-assembling nanobot, Berube concludes that E. Eric Drexler buried the concept under layers of rhetoric that were "detrimental to a coherent message that would have been helpful to the public." Faber (2006) examined the representations of nano in written and popular media from 1986 to 1999 arguing that the emergence of the topic in the popular media "occurred as a competitive and transitional social–rhetorical process" (p. 141). Although the accounts in the popular media were created within the established understandings of science they were also influenced by biographical and other social criteria of the research (such as religion).

Nanoscience and Visual Rhetoric

While only a handful of visual rhetoric studies have looked at nano images, each has focused on the rhetorical nature of the images because of how they are actively generated from a surface map. Hope (2004) points out that nanoscience images invite viewers to "participate in a magical transformation of the environment" (p. 9) because the images are displayed in high-color contrast and arranged into patterns and shapes that are pleasing to observe. She concludes that the images "work as powerful rhetorical constructs that allude to the sublime and the mysterious" and are "aesthetically compelling and mystifying" (p. 9). Similarly, Hanson (2005) mentions the mystifying nature of the molecular landscapes saying that nanoscience images communicate

more than a "new visible worlds" notion (like at the microscopic level) but that they also allude to computer-generated virtual worlds (p. 9).

Nanoscience and Images

At least one study has begun to look at the impact of visual images on the lay American audience specifically in relation to nanotechnology through inductive qualitative analysis using semi-structured interviews. Landau et al. (2008) first asked subjects about their general knowledge of nanotechnology and then recorded their reactions to two different visual images. The reactions from these two images revealed ten themes: "science, (medicinal) machines, technology, very small, sky, motion, (childhood) toys, bodily blood, injecting (disease), and foreign (insect)." Researchers conclude that these themes are evidence of polarities that exist in regard to science images. These polarities lead to flexible but also precarious public attitudes in response to nanotechnology.

In general, research concerning public perception of nano images is lacking. One of the few published studies concerning the public perception of nanoscience focused on two images and did not compare a selection of nano images from Robinson's image typology (2004)—schematics, documentation, fantasy, and fine art. Among the handful of articles that examine the visual rhetoric of nano images, the images are described and interpreted but there has been no comparison between these rhetorical evaluations and studies such as Landau et al. (2008).

Conceptual Framework

Goals and Context

The goal of this study was to determine how the rhetoric of four different types of nano images (fantasy, schematic, fine art and documentation) influence both public perception of nanoscience. Thus, the rhetoric of the four categories was considered according to the various groups of "public" available for the study (students, professionals, elderly, teenagers, etc.). Other intervening variables included personal experience with nanoscience, interest in science in general, the cultural background and/or religious beliefs of the individual and the context in which the image is viewed. In order to reduce variables, religion and cultural background (though important) were not considered for this initial study. Although context is very important for most rhetorical analyses[1], the images for this study were not analyzed within their original context. The images were taken from webpages, magazine covers, books, etc. and displayed without a background or information about the source during the rhetorical analysis and when shown to study participants. This is because the purpose for this rhetorical analysis was to determine the function of four different *types* of images if they would be used to inform the public. The concern was not with how the images function in a particular context, as with most rhetorical analyses, but with how each different type of image would function when introduced to a non-expert of the novel science. Context was not considered as far as where the image originated but with what context the viewer was most likely to associate the image. For instance, depending on the characteristics of the schematic image, a viewer might be reminded of a textbook and then would make judgments and evaluations based on that context.

Research Questions

By looking at schematic, documentation, fantasy and fine art images (Robinson's typology) it may be possible to determine if the response or perception of certain nano images relates to the style of the image. The following two research questions guide the analyses:

RQ1: In what ways does the rhetorical function of the nano image change depending on its "type"?

RQ2: How do audiences decode, or react to, various types of nanoscience images?

Methodology

Research Design

This study used a two-stage mixed methods approach to answer the research questions (Creswell, 2003). First, a visual rhetoric method was used to perform a close, systematic inspection of the images. According to Rice (2004), postmodern analysis of visual communication requires layers of approaches and methods (p.64). This study uses this layering approach to method by drawing upon a number of rhetorical concepts including: Foss's (1994) schema for visual rhetoric and more specifically her idea regarding the role of function in a visual analysis. A rhetorical critic believes, once an image is created, it stands independent of its

creator's intention because otherwise the possibilities for experiencing the image become limited. This study also uses elements of Gallagher, Martin & Ma's (2011) framework for visual wellbeing that utilizes the ancient rhetorical concepts of enargeia and eudemonia.[2] Using visual rhetoric as a method does not involve constructs and axioms that describe specific rhetorical components of visual imagery. In fact, as Foss (2005) points out, "the content that emerges from the application of the perspective is virtually limitless, bound only by the perspective's focus on how visual artifacts function communicatively" (p. 145). Furthermore, because studying the visual as symbolic persuasion is still a fairly new endeavor for most scholars of rhetoric, relatively few studies have been conducted that make connections to key constructs as a result of the insights produced by the application of the perspective. This is also partly because the visual rhetoric perspective has been applied to such a wide range of artifacts and rhetorical dimensions such as metaphor, ambiguity and argumentation.

After conducting the rhetorical analysis, a series of in-depth interviews was conducted in order to thoroughly collect opinions about the images and to suggest possible transferable findings from the sample population. In this way, (through a short demographic questionnaire implemented at the end of the interview) inferences about the perception of the population could be made (Babbie, 1990).

Although there have been a few studies regarding nanoscience images, rhetoric, and public perception, none of these studies has incorporated rhetorical methods with qualitative in-depth interviews. This two-stage mixed-methods approach allows researchers to interpret the meaning of images using their own rhetorical knowledge in addition to reactions of the interviewees.

Study Participants

For purposes of the interviews, a convenience sampling strategy was used (Patton, 2002). Similar to the Landau et al. (2008) study, participants were recruited by using personal social networks as a starting point in a large public university in the southeastern United States and approval for this study was obtained from the Institutional Review Board. Students and faculty of the university were not considered eligible for the in-depth interview portion of the study in order to "ensure that the social networking approach would reach out into the general community rather than back into the university" (Landau et al., 2008). Members of the public already participating in nanoscience research were also deemed ineligible because they may have already formed opinions of nanoscience images based on their higher-than-average knowledge on the subject. Most participants for this study originated from the southeastern region of the United States and interviews took place face-to-face. Because the research questions focus on how personal experience and culture work with the visual rhetoric of the image to influence knowledge and perception of nanoscience, a large heterogeneous sample of various ages, races, ethnicity, educational experience, etc. was desirable. Or, as Groat & Wang (2002) suggest, rather than selecting people to be interviewed through random sampling, the goal was to "maximize the variety and range of perspectives represented" (p. 174). The nature of the in-depth interview allowed for an initial sample of 25 people so that everything could be transcribed and thoroughly analyzed. Because of the possibility for future research in this area, participants were asked for demographic information to help highlight possible transferability of the sample and so other publics could be targeted.

Stimulus: Nanoscience Images

Fourteen images were chosen from a variety of sources on the Internet. At least three sources were chosen for each category to satisfy the "more-than-one" principle (Kaplan & Kaplan, 1982). Some of these images have also appeared in print form but the online images were chosen because some of the interviews were conducted online. The images were selected because they were tagged by whoever posted the photo with one of the words from the four categories (schematic, documentation, fantasy and fine art). They were also chosen because they were some of the most visited or linked-to images on the Internet (determined through a Google search). The images (in an uncategorized format) as well as the descriptions of the categories were given to a leading nanoscience communicator to check for reliability of the defined categories. The nanoscience expert placed the images in the same categories as identified by the researcher (and as tagged online)—demonstrating 100% reliability for the image categories. For additional information about the images chosen (origin, titles, creators, etc), please contact the author.

Method 1: Visual Rhetoric Analysis

To review, this study uses a layering approach of various visual rhetoric concepts and schemas. Often, scholars of visual rhetoric self-identify as "critics" because they believe the humanity of the researcher is "necessarily inherent" in the work (Sloan et al., 1977, p. 223). In other words, because humans are not mechanical or electronic machines, there will always be a contextual influence in a study. The term "critic" presents the researcher as an expert in the field and one who openly shares an evaluative viewpoint that is shaped by theoretical and social histories and perspectives. The Foss (1994) schema proposes that an artifact be judged on the function, rather than the purpose, of an image because "purpose involves an effect that is intended or desired." After identifying the function or various functions of an image, the critic also has the opportunity to evaluate an image, to assess whether it "accomplishes the functions suggested by the image itself" (Foss, 2004). Furthermore, most rhetorical scholars believe that artifacts should not be judged based on the intention of the creator. They are interested in the impact on viewers who do not have technical knowledge in areas such as design, art history or aesthetics. This attitude is similar to the assertions of visual communication researchers who argue that attribution and of implication/inference are essential to making interpretations of images (Worth & Gross, 1974; Messaris & Pallenik, 1977; Worth, 1978).[3]

Method 2: In-Depth Interviews

In-depth interviews consisting generally of three parts were conducted to gather participant reactions about the selected images. All interviews were conducted in the respondents' location of choice. The audio was recorded and then fully transcribed. The first portion of the in-depth interview process asked participants open-ended questions about what they knew about nanoscience/nanotechnology. Regardless of what the participants answered, another description of nanoscience/ nanotechnology was discussed with the participants so that all participants were somewhat aware of the image content prior to viewing. In order to determine how participants decode or react to nanoscience images and how the visual rhetoric of various images influences the public perception and knowledge of nanoscience (RQ2), the second portion of the interview presented participants with images on a computer screen (like they would view through online portals and websites) while corresponding open-ended questions were asked. Part three of the interview asked demographic questions as well as questions relating to previous experience and cultural background. Some of these categories (demographic and cultural) included: education, income, sex, age, past experience with nanoscience, interest in science, etc.

Data Analyses

Initially, the images' stylistic and substantive content was interrogated in order to determine how the visuals functioned rhetorically and how the variation in types altered the visual rhetoric (RQ1). In order to determine how the visual rhetoric of various types of nano images influenced public perception of specific images and public knowledge of nanoscience (RQ2), recordings and transcripts of the interviews were analyzed using a typological analysis framework that included processes of reducing the data, creating thematic categories, and drawing conclusions (Goetz & LeCompte, 1984; Miles & Huberman, 1994). The outcome of the inductive process resulted in three themes, far fewer than Landau et al.'s (2008) ten. The data was then given to an independent coder who was asked to code units into predefined categories (the three thematic categories identified). This step was conducted in order to determine the reliability of the units within the identified categories. Additionally, a test for intercoder reliability was run using Scott's Pi (Craig, 1981) that resulted in an acceptable 86% reliability. Also, in the results section, each of the research questions is referenced so that they could be answered in terms of thematic categories and the prior visual rhetoric analysis. Next, the findings from the initial visual rhetoric analysis with that of the thematic categories and information used to answer RQ2 were compared.

Visual Rhetoric Analysis

"Schematic" images, as explained by Robinson (2004), are the more traditional graph and diagram images of scientific visualization like line drawings and molecular models of the DNA spiral. Two of the three schematic images chosen for this study (see Figures 1, 2 and 3) are presented in black and white like the line drawings Robinson (2004) describes (or like traditional pen and ink drawings). Figure 2 of a carbon nanotube uses arrows and connecting lines to convey that one object is representative of another. Evidently, the flat honeycomb pattern in Figure 2 is intended to represent what the nanotube looks like prior to

the material being rolled. Figure 1 differs slightly from Figure 2 because it lacks any text and any kind of arrows or connecting lines.

Although it is a two-dimensional image, the more detailed shading and use of linear perspective creates the illusion of three dimensions. An attempt to illustrate a three-dimensional figure only occurs on the right half of Figure 2 in order to illustrate something flat that had been rolled. Figure 2 advances its pedagogical purpose through the use of arrows, vector lines and text within the images—an image similar to what would be found in a textbook or drawn on a board by a professor (most likely in even less detail).

Figure 1 presents an illustrative rhetoric that could also be found in a textbook but not for the intention of explaining how something works or its individual components but to provide students an illustrated idea of another world. The smooth and carefully composed lines created a vivid or enargaeic picture of a pristine landscape. Enargeia is a historical rhetoric construct that speaks to the ability to (re)create a vivid description, or present evidence as if it is present before the eyes of the audience. As Hanson (2005) points out in his argument about the use of landscape tropes in nanotechnology imagery, this kind of image allows viewers to explain "the less imaginable"… "in terms of the imaginable" (p. 3). Figure 1 serves as an artistic symbol that, as rhetorical theorist Nathan Crick (2011) explains, is intrinsically interesting to the imagination and engages an audience because of its aesthetic value.

This strategy assumes the viewer is aware of how the pieces fit together or that this kind of explanatory information is unnecessary because the image functions to illustrate a foreign concept and not its interworking. The shading, detail and perspective in Figure 1 invites viewers to enter the nano world and gives them a visual reference to consider the carbon nanotube. If the caption were not provided, a viewer may assume that the floating artifact above the sloping base of the illustration was constructed out of the same material. Furthermore, the use of perspective drawing, with one side of the tube opened toward the right, draws attention to the center of the nanotube. The attention to detail and the commitment to geometric shapes is reminiscent of the graphic artist M. C. Escher. Like Escher's images, the visual rhetoric of Figure 1 invites viewers to partake in a prolonged stare that evokes a tactile sensibility in viewers. The black and white detailing of another world is also reminiscent of Ansel Adams' photographs of Yosemite National Park that had a widespread impact on the park drawing visitors to it from all over the world. In fact, some have advocated for describing his work as landscape ideology (Berman, 1998, p. 115).

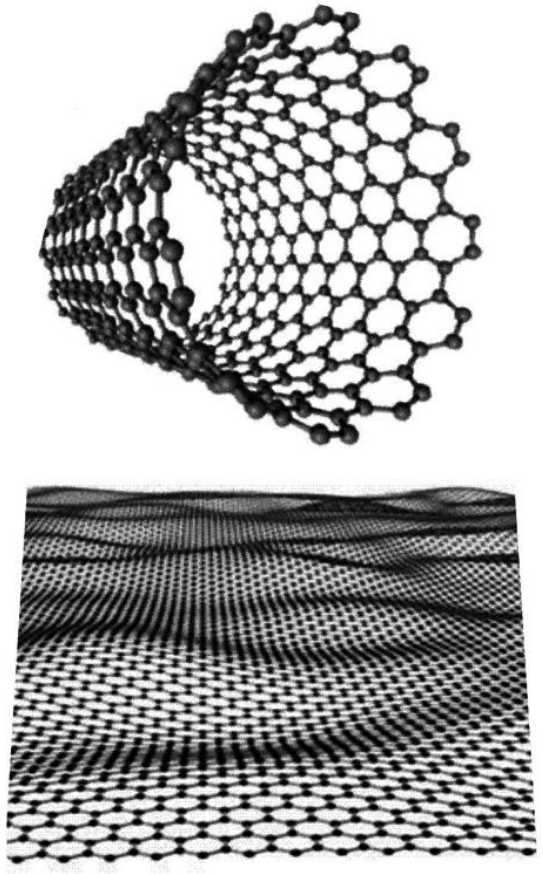

Figure 1. Schematic illustration of a single-walled carbon nanotube (top) and a graphene sheet (bottom)
Credit: Jannik Meyer

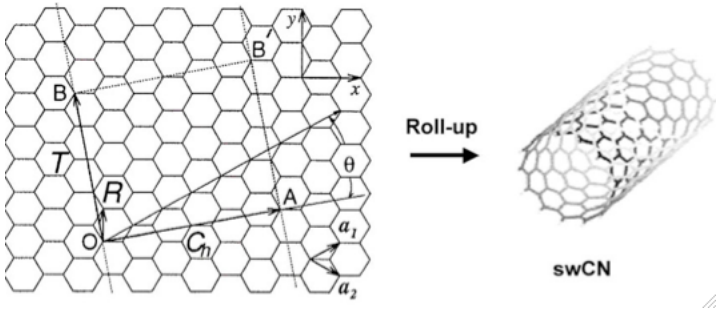

Figure 2.

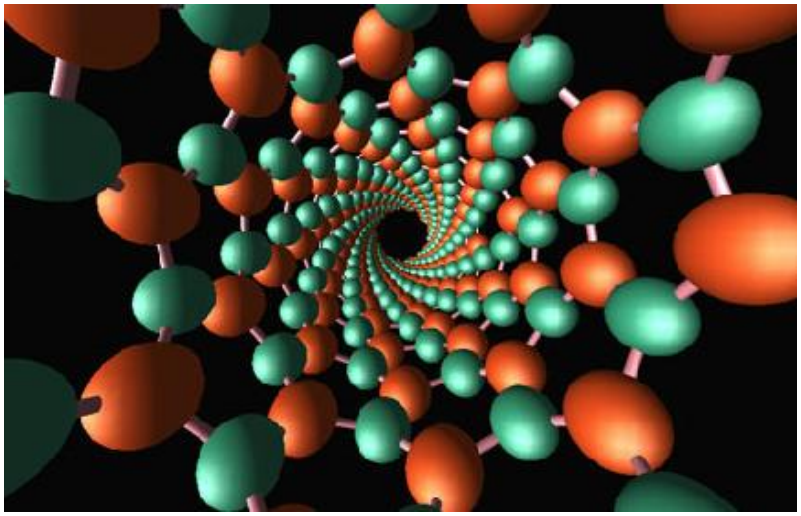

Figure 3. View down the middle of a boron nitride nanotube
Credit: V. Crespi

Figure 3, unlike Figures 1 and 2, consists of very bright orange and green coloring and is similar to the molecular modeling of DNA, another type of schematic image according to Robinson (2004). The shading of the spherical components and the use of the linear perspective create a three-dimensional effect that attracts the viewer to the center of the image. Because the center of the nanotube is arranged in the middle of the drawing, viewers have the sense of looking down the inside of the tube and may feel like they will embark on Alice's journey down the rabbit hole. The black background also suggests an unknown space like that of traveling through outer space. The visual rhetoric of this schematic image is much different than that of the black and white images. Although Figure 1 may present an idealized illustration of another world it does not convey the hypnotic feel, the power of the unknown and intimidation for some, as does Figure 3. The hypnotic feel to the image is not solely the result of the bright colors. Speculating about a similar scenario where Figure 1 uses colors of bright green and orange does not produce the same kind of mesmeric impact. Instead, the dramatic and captivating perspective and shading of the image is what most strongly contributes to the spellbinding rhetoric of Figure 3. Compared with Figures 1 and 2, an argument could be made to place Figure 3 under Robinson's (2004) "documentation" category instead of the "schematic" category because the schematic images are defined as having little "visual drama." With its strong use of linear perspective and vibrant colors, Figure 3 does utilize some visual drama. However, because it is so similar to the type of DNA modeling images that Robinson (2004) also defines as schematic, Figure 3 fits most neatly within this category. In summary, all three images would be considered "schematic" by the Robinson (2004) typology but only Figures 1 and 3 would be inviting to anyone not involved in some capacity in nanoscience research or education because the attention to aesthetics and the pedagogical rhetoric provides information that outsiders would not likely decode on their own. This kind of jargon-specific visual rhetoric would likely be alienating to an audience outside the world of nanoscience. Whereas the enargeic landscape imagery of Figure 1 invites viewers to become familiar with this new world of nanoscience.

Robinson (2004) continues his typology defining documentation images as "attempts to characterize how the image really is." This is usually done through the use of "photography, microscopy, illustration, and animation." One of the documentation images chosen for this study is in black and white (Figure 6) while Figures 4, 5 and 7 are in color. Similar to the schematic image (Figure 2), Figure 6 includes a horizontal line with the text "400nm" indicating the length of that line equals 400 nanometers. Although only one image is in black and white, two of the

four images have similar stylistic qualities in that they look like a photograph of a material at the end of a microscope. This photograph-like quality is due to the high contrast lighting (very dark blacks and very white light) and high resolution. Robinson (2004) writes that documentation images do not offer any additional insight or illumination but are created only because they look "cool". However, in the case of nanoscience it would seem that this kind of image functions in a similar rhetorical manner as Figure 1. For the world at the nanoscale, most people cannot envision what it could possibly look like without being given some sort of visual direction. Also, the documentation images speak to the myth of photographic truth where viewers assume photographs are evidence of the real (Sturken & Cartwright, 2001). Therefore, if the function of the image is to provide viewers a sense that nanotechnology is a currently used technology and less fantastical, then the documentation image would do well to convince much of the public. In this same respect, viewers may also begin to see nanoscience as "dirty" because a common educational experience with microscopes is to reveal the world of bacteria and dust (also common in commercials for cleaning products). The color in Figure 7 helps that particular image seem more appealing but even that visual content connotes objects such as cobwebs or a substance to be removed during a spring cleaning (somewhat ironic because the caption makes a point to mention that the image is of "cleaned" nanotubes).

The visual rhetoric of Figures 4 and 5 is similar to that of the rhetoric of schematic Figure 3 in that the colors and perspective for all three figures are bright and even a little intimidating. For both Figures 4 and 5 (also like Figure 3) an argument could be made to place them in a different category—in this case, the schematic category—because they are idealized versions of the subject matter. However, a better home exists in the documentation category because of Figure 4 and 5's "visual drama." Instead of being developed through microscopy, these two images are digitally illustrated and Figure 4 resembles Eigler's 'Electron Corrals,' one of Robinsons' (2004) examples of a documentation image. The illustration technique establishes an aggressive tone because of the bold colors and the digitized style. The very bright red paired with the yellow and the circle of spikes in Figure 4 communicates heat and sharpness, a grotesque style. The colors of Figure 5 are not as menacing as the red but they clash in such a way that a viewer cannot feel contentment in light of this dissonance—especially when the blue arrow abruptly shoots from above on the left side of the image. The arrow contributes to the militant feel of Figure 5 because it implies a strong move forward to a specified goal for the machines. The arrow also contributes to a sense of visual spectacle or a concoction that relies, as Aristotle (1954) had described, upon external factors (shock, sensation, and the passionate release) as a substitute for aesthetic integrity. It harshly slices through the picture and leaves a shadow creating a double slice straight through the image. The visual rhetoric of the digitally manipulated images may not disgust an audience but they are more aggressive and dissonant due to the bold and jarring color and configurations. It would seem that the intent for these documentation images is to make the unfamiliar world of nanoscience and its new developments more familiar for its audiences. However, due to the either very raw, unrefined shapes or the overly dramatized color, the dominant visual rhetoric may leave viewers with an uneasy attitude about the nature of nanoscience.

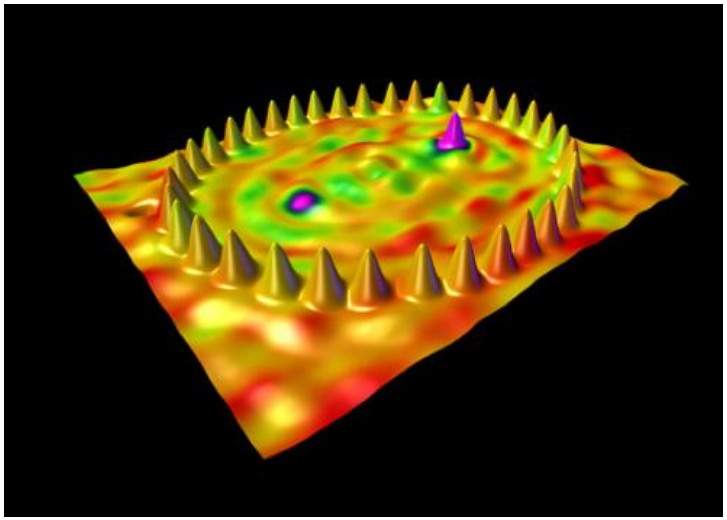

Figure 4. (available at http://people.rit.edu/knmgpt/)

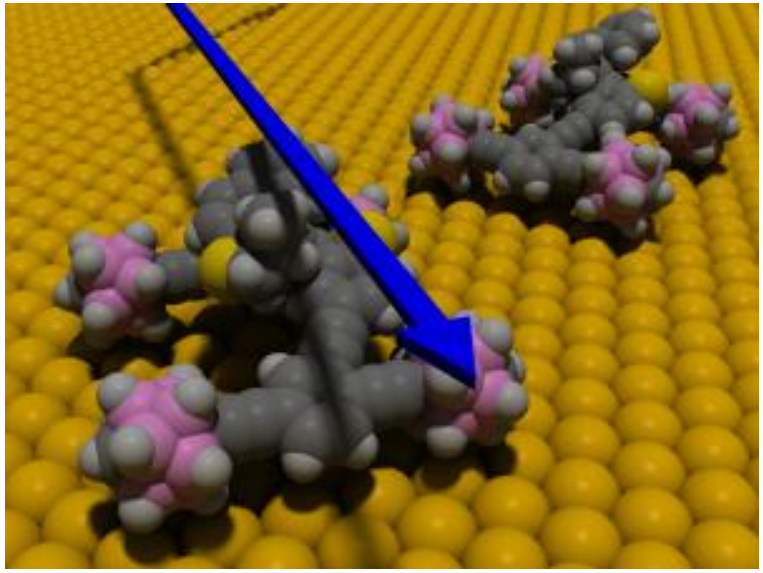

Figure 5. Nanocar
Credit: Rice University, J. M. Tour Laboratory

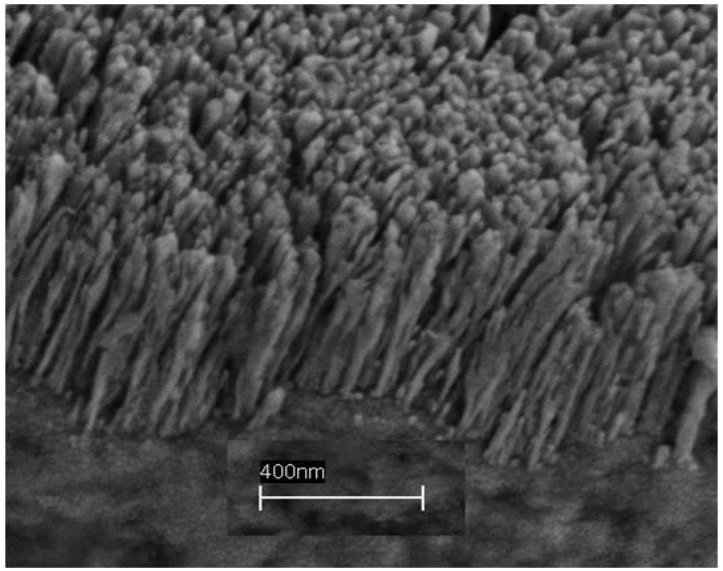

Figure 6. Copper nanorods deposited on a copper substrate
Credit: Rensselaer/Koratkar

"Fantasy" images, according to Robinson (2004), allow illustrators greater freedom in their depiction of nanoscience because it is more acceptable for the visual cues (lines, color, size, shape, etc.) not to be based in hard science. Robinson (2004) writes that these images captivate "at the risk of misinforming." If visuals were subject to the same rules of logic as text, these images might be accused of incorporating fallacious reasoning. These are the images most common in popular nano science fiction including characters such as monster-like mechanical devices, often shown in veins and arteries. Both of the images chosen for this study contain one foreign "mechanical device" (see Figures 8 and 9). One image (Figures 8) uses very bright colors whereas the other uses a style similar to the "documentation" images—a black and white and very detailed illustration that looks more like a photograph. However, even in the color image, the way in which the color is used is drastically different.

The red blood cell image uses only variations of red, most likely to convey to audiences that the mechanical device is within a human bloodstream. The colors in (Figure 8) are reminiscent of images of the fantastical genre, with very bright neon pastels that change throughout the matter in a random fashion and appear to glow.

In these fantasy images, the mechanical devices are made distinct from the surrounding environment through the use of straight lines and smooth, sharp edges. As Robinson (2004) alludes, the mechanical devices in the images do not reference any kind of human control. One of the mechanical devices (Figure 9) seems to maneuver freely throughout a nanoscale worlds while the second image (Figure 8) appears to have descended from another entity above (this could or could not be human-related. What is most interesting with these images is that their rhetorical functions appear very divergent.

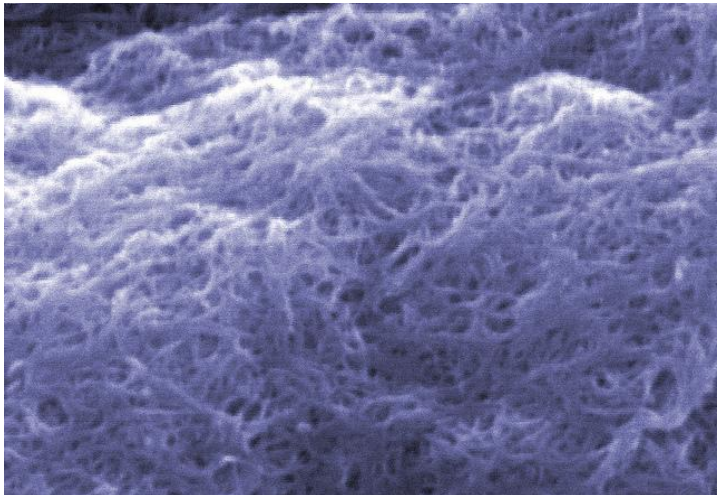

Figure 7. Scanning electron microscope image of 'cleaned' carbon nanotubes at NIST (color added for clarity.)
Credit: National Institute of Standards and Technology *(NIST).*

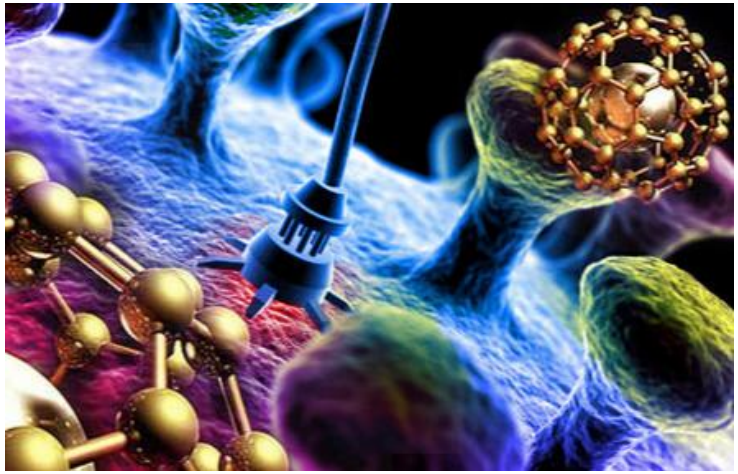

Figure 8.

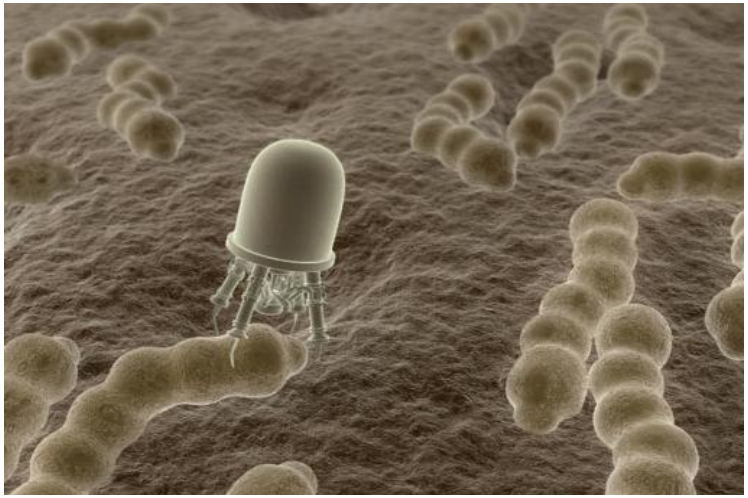

Figure 9.

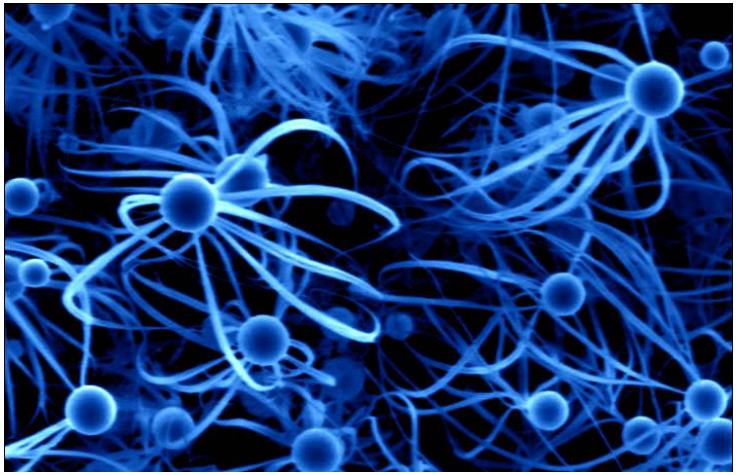

Figure 10. Ga ball-Si crystal-SiOx nanowire octopus.*Credit:* Oak Ridge National Laboratory for the Department of Energy (ORNL).

Someone seeing these images is led to think, these are the kinds of things happening with nanotechnology or could happen one day soon. However, because the mechanical devices appear to float about freely without reference to human control, this also creates an anticipatory rhetoric due to the variety of potential outcomes. Autonomous micro machines may navigate efficiently and accomplish their goals or they may go rogue fostering mayhem and destruction in their wake. Figure 8, although it has intriguing and attractive colors and imagery, does not provide viewers with any reference to a world with which they are familiar. The mechanical-device most likely would allude to something having to do with outer space as well as the world the mechanical device is entering—even the golden spheres float in the atmosphere suggesting no gravitational pull or perhaps a world under water. This suggests that nanoscience borders on fiction or deals with issues unrelated to the real-world. In short, the rhetoric of the fantasy images instills a rhetoric of just that—fantasy. The visual rhetoric exemplifies excitement for the possibilities but it also implies suggestions for how the most cutting edge technology could be invasive and also unresponsive to human demands.

As defined by Robinson (2004), the creators of fine art images seek "some form of meaningful and long-term effect on culture." Robinson (2004) claims that artists should be involved in scientific visualization because they "have the ability to mediate complex information and assist in the public's understanding." All four "fine art" images analyzed in this study are in color (Figure 10, 11, 12 and 13). Three of the images consist of mainly one color (all of the these colors are very bright and not seen as commonly in nature). Although the images do not appear animated or illustrated, they also do not look like something under a microscope (at least according to most people's experiences with microscopes). Instead, the colors are vibrant but not overwhelming and the form is very aesthetically pleasing. When compared to the other images, this group is definitely the most organic. The few straight lines that are depicted, like in Figure 13, are contrasted with more sporadic and unpredictable lines that jut out within the geometric shape. In Figure 12, with its perfect symmetry, the image appears like it could change at any moment.

This dynamic feeling is most likely because the beads appear to grow from the center of the image, leaving the viewer to wonder if the beads

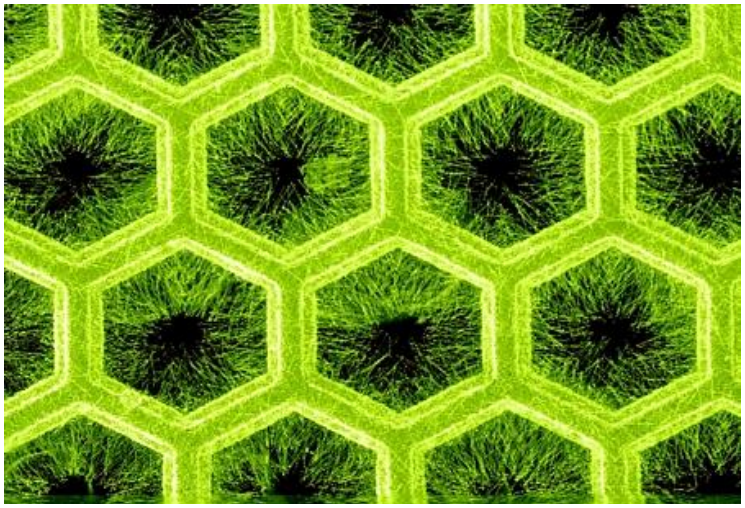

Figure 11. Germanium-catalyzed ZnO nanowire.
Credit: Oak Ridge National Laboratory for the Department of Energy (ORNL).

will sink back into the center or continue to grow outward. The visual rhetoric of these images created through their beauty intrigues viewers, and fosters *eudemonia*, the ancient rhetorical term for flourishing or fulfillment (Gallagher, Martin & Ma, 2011). Instead of quick glances, the magnetism of the images, due to their organic form and vibrant but appealing colors, manage to alleviate many negative associations people have with science—feelings of intimidation, unreality, scariness and even disgust. The use of aesthetically pleasing symmetry, shapes and colors indicates that the intent of the fine art images is not to surprise or upset an audience but to draw their attention to the image and prompt them to consider the content.

Qualitative Analysis of Interviews: Decoding Nanoscience Images (RQ2)

In the Landau et al. (2008) study, researchers argued that for "non-scientists" visual images of science are drawn from and fixed back within a specific "visual' domain of 'science' images" (p. 9). They arrived at this conclusion after inductively identifying 10 different themes resulting from interviews of people responding to two nanoscience images. The themes identified within this study however, were much more broad and

thus did not result in the same conclusion. Only three themes were identified when analyzing the interview data (RQ2), 1) science education (Landau et al. referred to this as "images of science" 2) science fiction and 3) everyday objects and situations. These themes were identified across all four of Robinson's typology of nanoscience images. Observations of participant reactions according to each typology are discussed following the description of the themes.

Science Education

This theme demonstrated how participants identified certain types of image techniques as similar to other images they have witnessed in science and math classes, science textbooks and science journals and magazines. Interestingly, there was not one specific type of science image that participants most often identified with science education. A majority of participants did mention that Figure 2 (a schematic image) reminded them of school in some way but at least one image from all three other typologies had participants mention that it reminded them of school. Participants decoded images using their experiences with science education in the following examples:

> This looks like an x-ray of bacteria. Like something is moving or we're getting information from it. It looks gross or moldy. The lack of color gives me this impression. This looks like a slide you would look at in high school that was bacteria laden. It looks like dust mites or something. (Figure 9: fantasy image). This is not as exciting [as images viewed previously]. This looks like a drawing just to talk about it, like its just trying to get information out there. Maybe like it would be used to teach what it could be. I feel like you would see it in a textbook and learn it for a test so this doesn't give me good feelings because it looks boring and difficult. There seems to be a lot of information on here. There are lots of letters, and arrows, etc. (Figure 2: schematic image).

> It makes me think of school, like a diagram or something in a textbook, like something explaining the synthetic process. It gives me dread because it reminds me of something on a test It looks like they sprung from each other. The arrow and the colors don't go well together, they're not pleasing and it reminds me of a textbook. (Figure 5: documentation image)

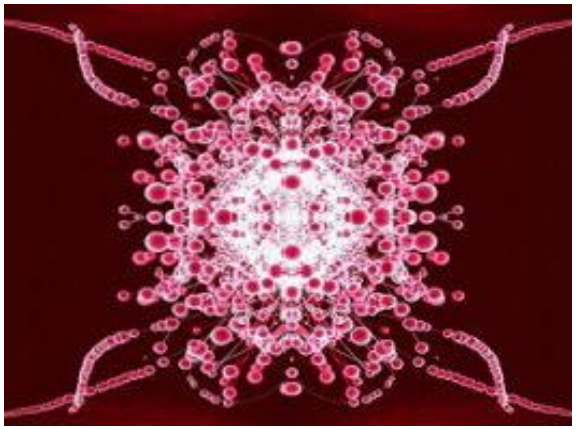

Figure 12. Germanium beads chain.
Credit: Oak Ridge National Laboratory for the Department of Energy (ORNL).

Figure 13. Germanium-catalyzed ZnO nanowire on a copper grid.
Credit: Oak Ridge National Laboratory for the Department of Energy (ORNL)

When participants were asked to further explain what they meant when they said it reminded them of a certain class they would often follow up with, "it looks like an image you would see in a/n [insert science or math course here] textbook." Sometimes participants were more specific, noting that especially for the fantasy images (not that they identified them as such because they were not labeled) they would more likely be on the cover of the textbook. For example, one participant said of Figure 8, "I feel like this should be on the cover of a science book. Like in the two corners they look like they would be some weird atomy molecule jazz, and this center thing looks like a plug going into an outlet, and these look like they are exploding." As illustrated in the few examples above, a general emotion associated with the "Science Education" theme is often negative with participants feeling frustrated or bored with their lack of knowledge or they associated the image with a distasteful experience from the classroom. More examples of this follow:

> This makes me think of something that I don't understand. It makes me feel kind of retarded. Like, maybe I should know this stuff. It makes me want to go the other direction. I mean what does this stand for? Why does it have an x and y axis in the middle of the folded rollup? What do the letters stand for and why? We've got different angles and lines. Some are thick and some are dotted. It makes me think nanoscience is extremely complex. Ridiculously complex. (Figure 2: schematic image)

> I thought of seaweed or something at the bottom of the ocean. I guess this makes me confused. I don't understand what is going on. It looks like it's from a microscope. (Figure 6: documentation image)

> I guess it kind of grosses me out. If you zoom in it looks webby. In microbiology we learned about pathogens and ecoli and the intestines are lined with the epili and so it kind of reminds me of that. So it kind of grosses me out. (Figure 6: documentation image)

Science Fiction and Outer Space

This theme illustrated how participants would decode certain images by relating them to popular movies or books and their conception of outer space. Although the argument could be made to separate outer space as a theme in and of itself, it was paired with science fiction for this study because participants almost always treated them synonymously (This is also similar to how they treated the words "molecules," "atoms," and "cells" where the terms were used interchangeably). For instance, this was one participant's reaction to Figure 8, "Outer space. Like an explosion? No, not an explosion but its got a lot going on. It's interesting and I kind of like it. Sci-fi. Like something you've seen in a movie." Not so surprisingly, participants most often used the "science fiction" term when describing their reactions to the fantasy images.

Every Day Objects and Situations

The "every day objects and situations" theme illustrates that participants may decode nanoscience images using familiar objects and situations related to the science genre, but whether or not it is science related really depends on their own personal interpretations and take on the image. Very often participants made non-science related everyday associations having to do with personal experiences from their own past or media they've seen, like:

> This makes me think of jellyfish because I went to a restaurant that had a fish tank with jellyfish in it that had a blue light underneath it so all the jellyfish lit up blue. I like this image because of that memory. (Figure 10: fine art image)

> This looks like an infrared image of a cult-like ceremonial structure, almost like Stonehenge. It also looks like Bart Simpson's spiky hairdo. I don't know whether to think it is funny or creepy. (Figure 4: documentation image)

> Really it looks like Christmas. It looks like the webbing around a Christmas tree. It makes me feel itchy. I'm allergic to pine trees. It looks like Christmas trees when it is wrapped up in that plastic wrap when you buy it from the boy scouts on the corner. (Figure 11: fine art image)

> This reminds me of the scrubbing bubbles commercial but on a really dirty bathtub. The shapes are similar and the lack of color makes me think it is dirty. (Figure 9: fantasy image)

Therefore, it did not appear that participants were making any attempt to relate their reactions to science. Even with Figure 2 (the image that most participants associated with science education) there was the occasional association with the everyday. For example, one participant said of the schematic figure, "This image looks like honeycomb or a fruit rollup." Another said that the image looked like a "Parmesan cheese rollup" that she had seen a chef create on the Food Network. These descriptions fit better under an alimentary category as opposed to science.

Typology and Other General Observations (RQ2)

Many of the typology observations in this study support Robinson's (2004) assertions and recommendations regarding best strategies for depicting nanoscience visually to the public. Robinson (2004) questions the usefulness of the documentation image when communicating scientific ideas because of their extreme manipulation and inaccuracy. The qualitative data from this study, does suggest that documentation images may not be the right approach to build public understanding and enthusiasm for the novel science. Although there were a wide variety of reactions to the documentation images, the emotional reactions were generally negative in response to all of them. The illustration images received some of the most divergent descriptions There were the occasional positive comments but these reactions were definitely in the minority and were sometimes changed by as the viewer spent more time with the image.

By contrast, participants appeared to have a much different experience when viewing the fine art images. They usually described these images as giving them "happy" or "peaceful" feelings and commented on their "symmetry" sometimes describing them as "pretty" or "aesthetically pleasing." Figure 12 was the only fine art image that had more mixed reactions from the participants. Although they also described Figure 12 using words like "symmetrical" and "interesting" most of them also thought it resembled a bug and so would also describe it as "creepy," declaring that bugs are "gross" or make them "nervous." This seems to suggest that whatever content association participants had with the image was the most powerful determining factor in their general like or dislike of the image. This also supports the findings of Worth & Gross, (1974); Messaris & Pallenik (1977) and Worth (1978) that suggest attributions are essential to making interpretations of images.

Figure 13 (another fine art image) was the image participants liked the most with almost every participant saying that the image reminded them of wild gardens specifying the action of blowing the seeds from the top of a dandelion. Like the participant who said she liked an image because it reminded her of a specific memory (Figure 10), this kind of specific and personal association to a positive or negative experience was crucial to the final opinion of an image. Robinson (2004) suggests artists would be the best mediators for the cultural role for nanoscience and the results of this study appear to support this claim because participants definitely spent the most time with, and reacted most positively, to these images.

Figure 1 however, did not draw any negative reactions but instead a wide range of scientific and everyday associations including: Dali artwork, M. C. Escher artwork, desert dunes, Chinese handcuffs (childhood toy), molecules/atoms, afghan blanket, basket ball net, yellow brick road and a waste basket. These associations produced descriptions of feelings such as curious, cool, creative, neutral/matter of fact, and soothing. Like the fine art images, it seems telling that participants compared this image with famous artists instead of associating it with an image in a textbook.

Implications

It may seem surprising that fewer themes were identified in this study with 13 images presented to interview participants than the Landau et al. (2008) study only presented two images. However, because the variations in the reactions to the images were so numerous the themes identified would have to be very broad to encompass this variation. This only further supports Landau et al.'s (2008) later argument that "polysemy exists in the memories and attitudes of the individual" (p. 10). Because of the polysemic nature of images and the participant's memories and attitudes, perhaps even more so with ambiguous science

images, the themes identified would have to be very broad given the number of images, types of images, and participants. The results of this study contradict Landau et al.'s (2008) earlier assertion that "lay people" will refer back to the domain of science images. Although quite often participants did refer back to science images, there were many times (even when the participant was more familiar with nanoscience) when they would simply react to an image according to whatever everyday image or situation first popped into their head, regardless of whether or not this association was even remotely related to science.

Another compelling finding to note is the way in which the images were created (whether they appeared more manipulated or more like photographs or drawings) did not determine whether or not participants had more positive or negative responses. These findings suggest that other factors, such as personal associations, color and lighting are much more important to the outcome of participant reactions than the way in which it is created. These findings support the notions of rhetorical scholars as well as visual communication researchers Worth and Gross.

Though context was purposefully excluded from this study, future research should provide viewers with specific contexts in order to observe how viewers may change (or not change) their interpretations and how these contexts may play a role in public perception and understanding.

Reflections on mixed methods

Conducting a visual rhetoric analysis of the nanoscience images along with the in-depth interviews, helped answer some of the inevitable questions about participant reactions. For instance, just as the rhetorical analysis anticipated, participants' reacted negatively to Figures 2 and 3 because of their educational experiences and need for explanation or associations with school. By contrast they did not have the same negative associations with schematic Figure 1. The rhetorical analysis also provided a more concentrated perspective with an abundance of data. The qualitative data illustrated how people reacted to a variety of images but the rhetorical analysis helped explain how the rhetoric of the image influenced these reactions. The qualitative data also provided information for a deeper understanding of how people decode the image's rhetoric. For instance, the rhetorical analysis of the fantasy images mentions two different messages, 1) excitement for progressive possibilities as well as 2) nervousness about loss of control. The qualitative data illustrated that the latter message was the stronger of the two according to the responses by this group of interview participants.

Furthermore, this study also revealed the interesting relationship between rhetoric and aesthetics. Although there has been some effort to divorce visual rhetoric from aesthetic concerns (Foss 1994; Peterson, 2001), the idea being that attention should be drawn away from creators' intentions and artistic concerns and toward the function of the visual image itself, this study suggests that aesthetics play a large role in the persuasive process. The fine art images, the images with the highest concern for aesthetics and that used aesthetic principals in their construction, were the images that participants enjoyed looking at the most and, according to both the qualitative and rhetorical analysis, invited a more prolonged and thoughtful look.

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Endnotes

[1] In fact, visual rhetoricians sometimes see the dismembering of the visual artifact as potentially narrowing the researcher's ultimate understanding. Their worry is that looking specifically at color or shape as distinct elements aside from their environmental relationships may prevent the researcher from grasping the larger picture and how the elements interact with the audience and the surrounding environment. For the rhetorician, the rhetorical function of the visual artifact as a whole is the most important issue to address.

[2] For a framework of characteristics of enargeia and eudemonia see tables 2 and 3 in Gallager, Martin & Ma (2011).

[3] Attribution or communicational inference are terms used by Worth and Gross to describe what viewers know about the subject matter prior to viewing the image and not any kind of meaning located within the picture.

Summary of Findings

Rhetorical Analysis Findings

- Enargaeic images depicting a vivid landscape work, even if they are the traditional graph and diagram schematic images, would be well received by non-expert audiences. They serve as an "artistic symbol" that enage the audience through aesthetic value.

- Like certain popular artists, nano images reminiscent of landscapes and with a commitment to detail invite viewers to partake in a prolonged stare that evokes a tactile sensibility in viewers.

- Educational references within ***schematic*** images provide information that outsiders would not likely decode on their own. This kind of jargon-specific visual rhetoric would likely be alienating to an audience outside the world of nanoscience.

- ***Documentation*** images speak to the myth of photographic truth where viewers assume photographs are evidence of the real. They also provide viewers with a sense that nanotechnology is commonly used and not a technology in the distant future.

- Digitally manipulated images should be careful to avoid an aggressive and dissonant rhetoric due to bold and jarring color and configurations. These visual decisions may leave viewers with an uneasy attitude about the nature of nanoscience

- ***Fantasy*** images may highlight possibilities for the technology but they also make implications for how the technology could be invasive and unresponsive to human demands.

- ***Fine art*** images foster *eudemonia*, the ancient rhetorical term for flourishing or fulfillment. These images manage to alleviate many negative associations people have with science—feelings of intimidation, unreality, scariness and even disgust. The use of aesthetically pleasing symmetry, shapes and colors, indicates that the intent of the fine art images is not to surprise or upset an audience but to fully draw their attention.

Qualitative Findings

- Unlike Landau et al.'s (2008) identification of 10 nanoscience image themes, only three themes were identified 1) science education 2) science fiction and 3) everyday objects and situations. These themes were identified across all four of Robinson's typology of nanoscience images.

- Responses suggested that whatever content association (or attributions) participants had with the image, this would be the most powerful determining factor in their general like or dislike of the image.

- Landau et al.'s (2008) finding that "lay people" will refer back to the domain of science images was contradicted. Viewers would simply react to an image according to whatever everyday attribution popped into their

head, regardless of whether or not this association was even remotely related to science.

- The process and medium in which the images were created did not determine whether or not participants had more positive or negative responses

Additional Findings

- Artists would be the best mediators, using visual communication, between scientists and the public.

- The rhetorical analysis helped explain how the composition of the image influenced reactions. The qualitative data also provided information for a deeper understanding of how people decode the image's rhetoric

- Although there has been some effort to divorce visual rhetoric from aesthetic concerns, this study suggests that aesthetics play a large role in the persuasive process. The fine art images, the images with the highest concern for aesthetics, were the images that participants enjoyed looking at the most and, according to both the qualitative and rhetorical analysis, invited a more prolonged and thoughtful look.